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Soft Particle Spectrometer, Langmuir Probe, and Data Analysis
for Aerospace Magnetospheric/Thermospheric Coupling Rocket Program

by

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ABSTRACT

Under this grant two instruments, a soft particle spectrometer and a Langmuir probe, were refurbished and calibrated, and flown on three instrumented rocket payloads as part of the Magnetosphere/Thermosphere Coupling program. The flights took place at the Poker Flat Research Range on February 12, 1994 ($T_0 = 1316:00$ UT), February 2, 1995 ($T_0 = 1527:20$ UT), and November 27, 1995 ($T_0 = 0807:24$ UT). In this report the observations of the particle instrumentation flown on all three of the flights are described, and brief descriptions of relevant geophysical activity for each flight are provided. Calibrations of the particle instrumentation for all ARIA flights are also provided.

INTRODUCTION

At auroral latitudes, magnetospheric processes provide energy sources to the thermosphere which can at times exceed that from solar EUV sources. Energy is imparted directly by particle inputs and momentum is imparted to the neutral gas by from the motion of ions in the electric field. The objective of this program was to study the effect of these influences on thermospheric densities, temperatures, composition, and winds. This was accomplished by launching an instrumented payload into the thermosphere which had been heated by the presence of steady diffuse aurora. Coordinated with the flight of the instrumented payload were flights of chemical release payloads employed to determine the thermospheric wind patterns. This combination of instrumented and chemical release rockets were launched from Poker Flat Research Range in three separate campaigns: on February 12, 1994 ($T_0 = 1316:00$ UT), February 2, 1995 ($T_0 = 1527:20$ UT), and November 27, 1995 ($T_0 = 0807:24$ UT).

This program has been designated as ARIA II since it is a continuation of the ARIA I (Atmosphere Response in Aurora) program (Anderson et al., 1995), in which an instrumented payload was launched on March 3, 1992 into a post-midnight diffuse aurora. The first ARIA flight was very successful and has resulted in at least four papers in the literature (Anderson et al., 1995; Hecht et al., 1995); Brinkman et al., 1995; and Larson and Walterscheid, 1995).

The observations of the ARIA II flights have been discussed in papers presented at the AGU and are in various stages of analysis for written publication. In this report we describe the observations of the particle instrumentation flown on each of the ARIA II flights and provide brief descriptions of relevant geophysical activity.

FLIGHTS

ARIA 2

ARIA 2 was also designated ARIA-Kayser, after Dave Kayser, who contributed greatly to the success of the first ARIA mission. It was launched into a post-midnight diffuse aurora on

February 12, 1994 at 1316:00 UT. The electron data are shown in the spectrogram of Figure 1 which also shows a plot of the electron energy flux ($\text{erg}/\text{cm}^2\text{s sr}$); the payload altitude is shown in the lower panel. As can be seen in the spectrogram, the Soft Particle Spectrometer (SPS) initially measured quasi-thermal electron spectra in the energy range of the primary auroral electrons (several hundred eV to ~ 20 keV). These spectra may often be represented by unaccelerated Maxwellian or Kappa distributions. At lower energies, the secondaries contribute to a power law spectrum of negative slope. During the flight, just past apogee, the payload passed through two low-energy auroral "arcs," characterized by accelerated Maxwellian spectra peaking at ~ 400 eV. Examples of these spectra are shown in Figure 2. The quasi-thermal spectrum was measured between 256 and 260s; the arc spectrum was measured between 280 and 284s. The arcs were also detected by photometers both on the ground and in the payload. A study of this event is underway; initial results were presented at the Spring 1995 AGU (Hecht et al., 1996).

The positive ion data, shown in the second panel of Figure 1, indicate little structure in the relatively low intensity incident ions. The intensity appears to decrease slightly throughout the flight as the payload moves northward. The structure at energies below about 30eV is instrumental. It results partly from a rammed-in ionospheric component due to an inadvertent grounding of the ion grid on this flight.

ARIA 3

ARIA 3 was launched at 1527:20 UT on February 2, 1995 into a late morning diffuse aurora (local time of launch was 0627:20). The flight took place during the recovery phase of a magnetic substorm that reached the peak of its expansive phase minutes before 1500 UT. As recovery was taking place, another smaller expansion began very near the time of launch. Relatively high absorption and E-region winds were measured by ground instrumentation at Poker Flat. The absorption, measured by the range riometer, is indicative of incident high-energy particles that lose their energy in the D-region, and this is suggested by the electron spectrogram of Figure 3, although the SPS range of energy measurement does not exceed 27 keV.

The SPS was turned on at $T + 86$ s into the flight at a height of 116 km. At turn-on the payload was within the emission region of an auroral form characterized by electron peak energy fluxes of a few $\text{erg}/\text{cm}^2\text{s}$ and energies of ~ 3 keV (see spectrum shown in Figure 4a). For the next four minutes the spectra were generally quasi-thermal showing occasional variations in intensity. On the downleg starting at about $T + 325$ s, the payload again passed through an auroral form containing two regions of enhanced fluxes. The primary energies of these enhanced regions were ~ 1 keV ($T + 365$ s) and ~ 2 keV ($T + 400$ s). A spectrum measured at $\sim T + 396$ -397s is shown in Figure 4b. The payload passed out of the region of enhanced fluxes at $T + 415$ s just before SPS turn-off at $T + 420$ s. It can also be seen in Figure 3 that the low-energy electron fluxes were enhanced each time the payload passed through a region of enhanced primary fluxes. It is to be noted that the Electric Field Experiment (R. Pfaff, P.I.) detected waves in the ~ 2 to ~ 5 MHz range at times corresponding to the first and last enhancement regions encountered. These regions showed the highest primary energies, the highest intensities of low-energy fluxes, and

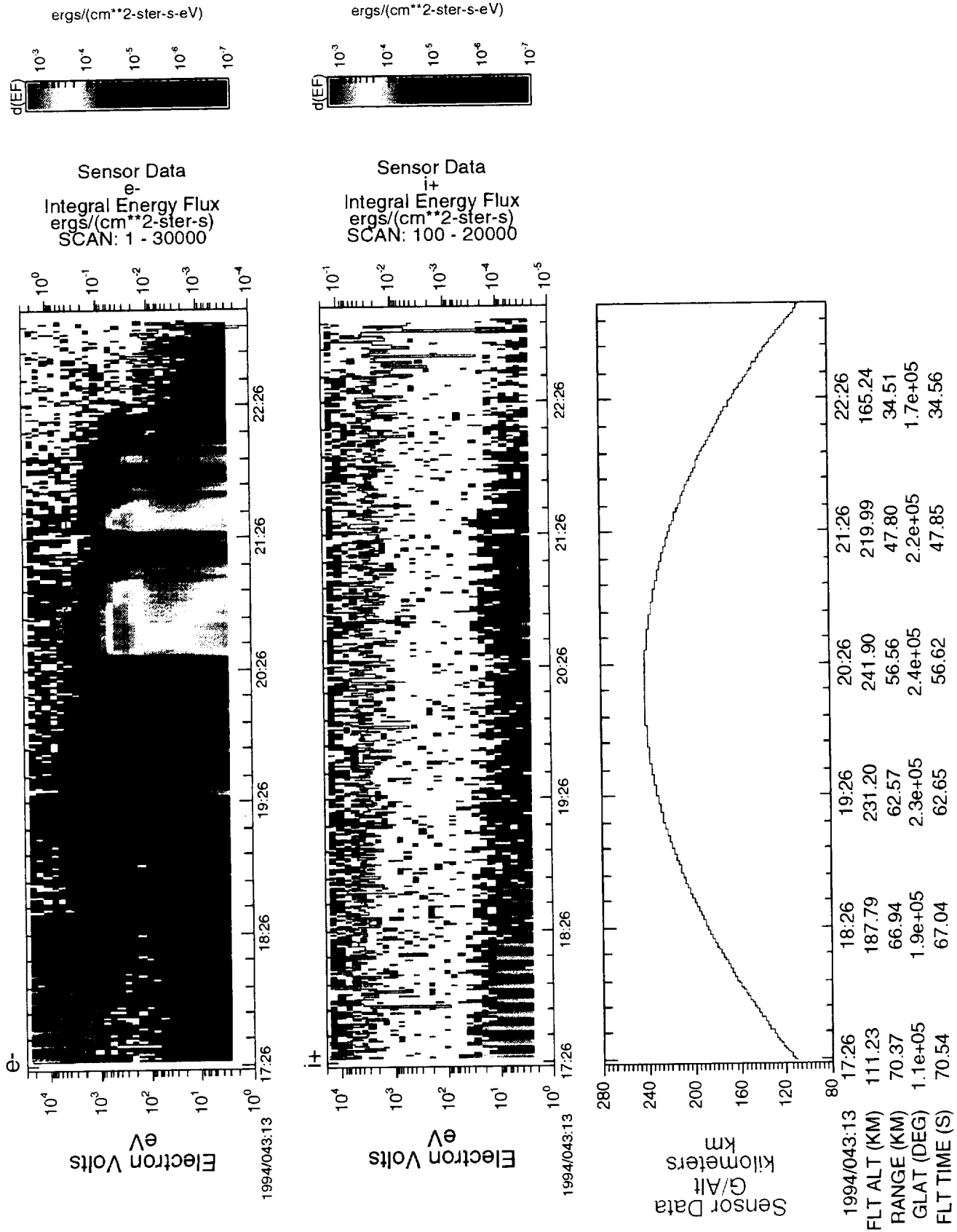


Figure 1. ARIA 2 electron and ion spectrograms and altitude plot. Energy flux (in erg/cm2 s sr) is shown in red in each spectrogram. Horizontal range, invariant range, and flight time are shown below the data panels.

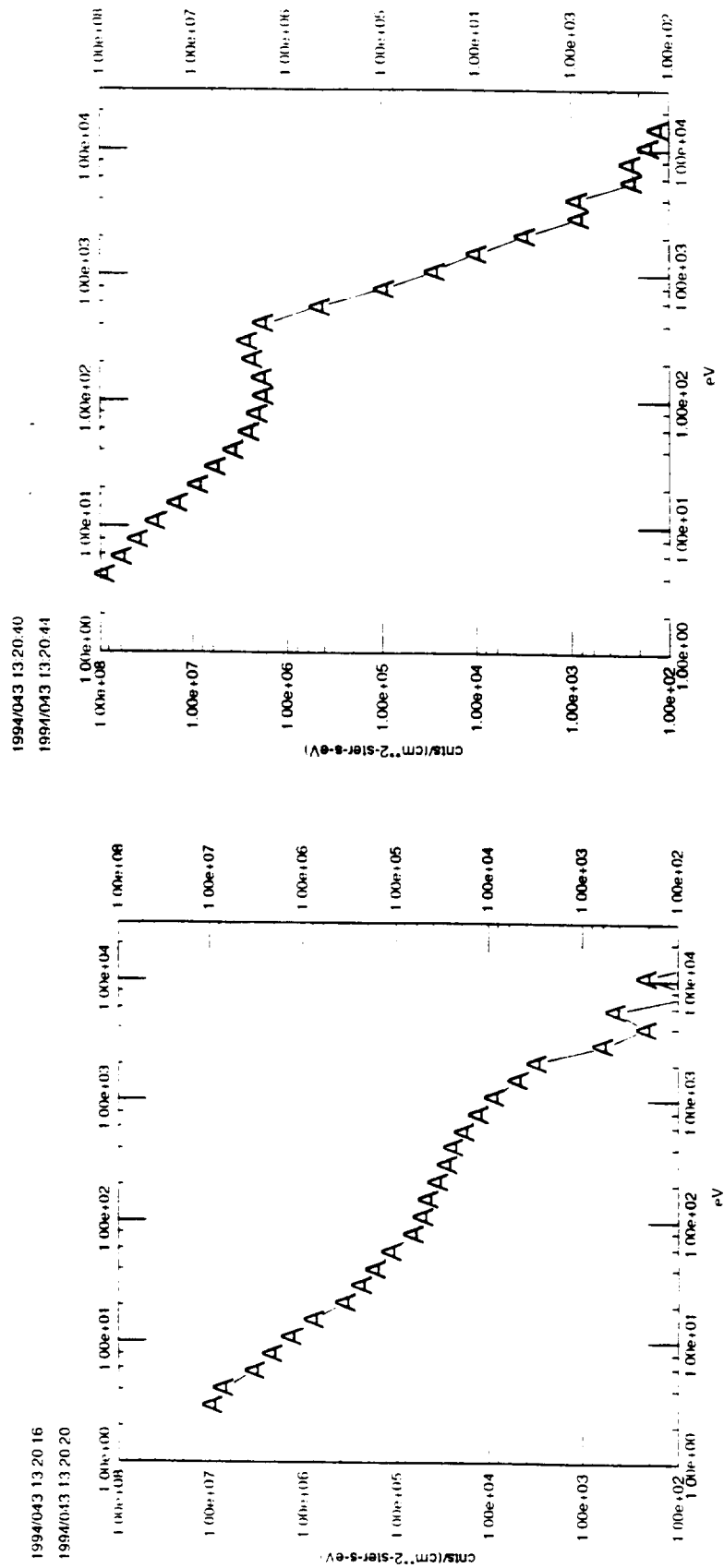


Figure 2. ARIA 2 electron spectra showing quasi-thermal spectrum measured at 258 s into the flight (left) and accelerated Maxwellian spectrum measured at 282 s (right).

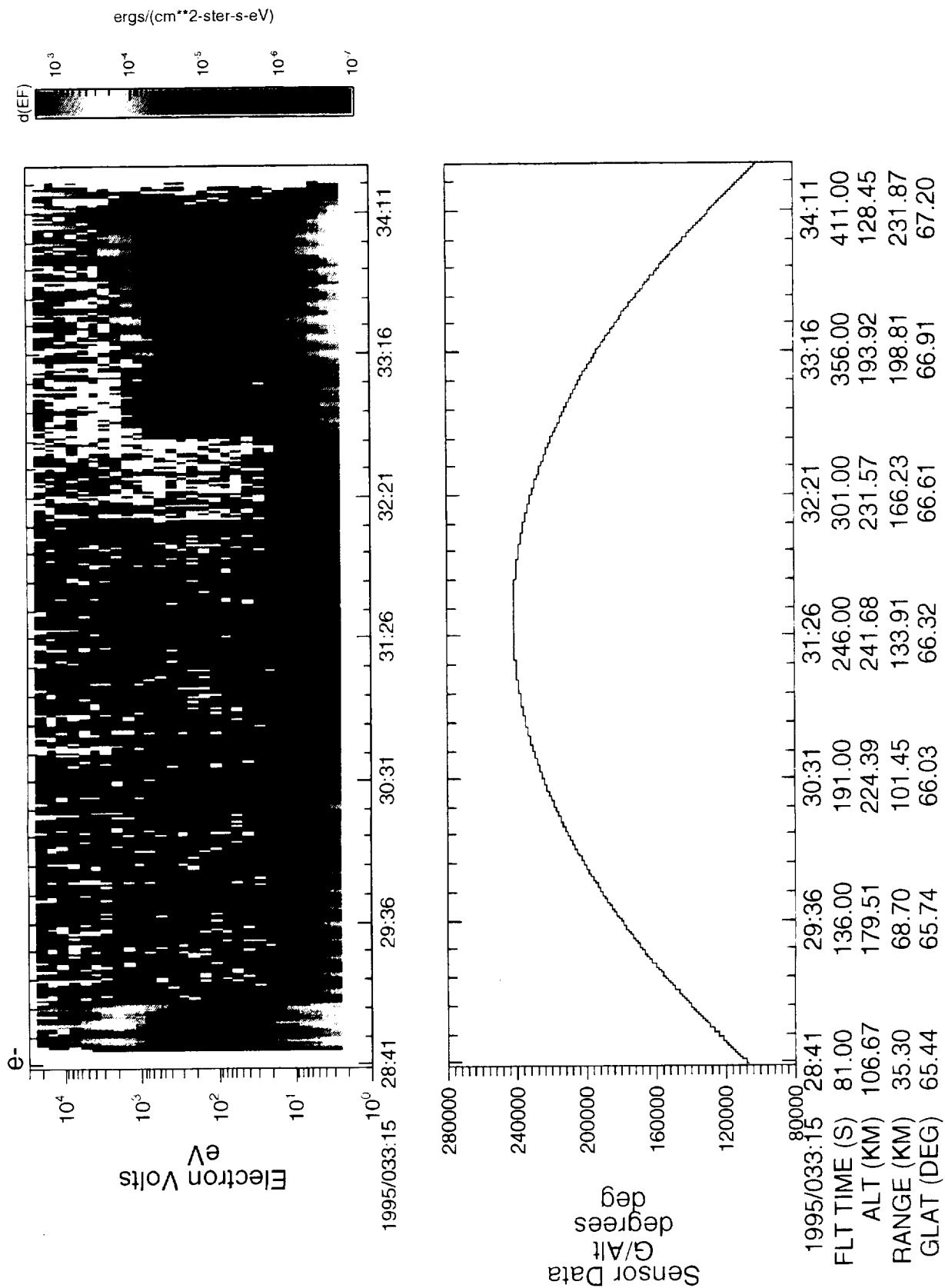


Figure 3. ARIA 3 electron spectrometry and altitude plot.

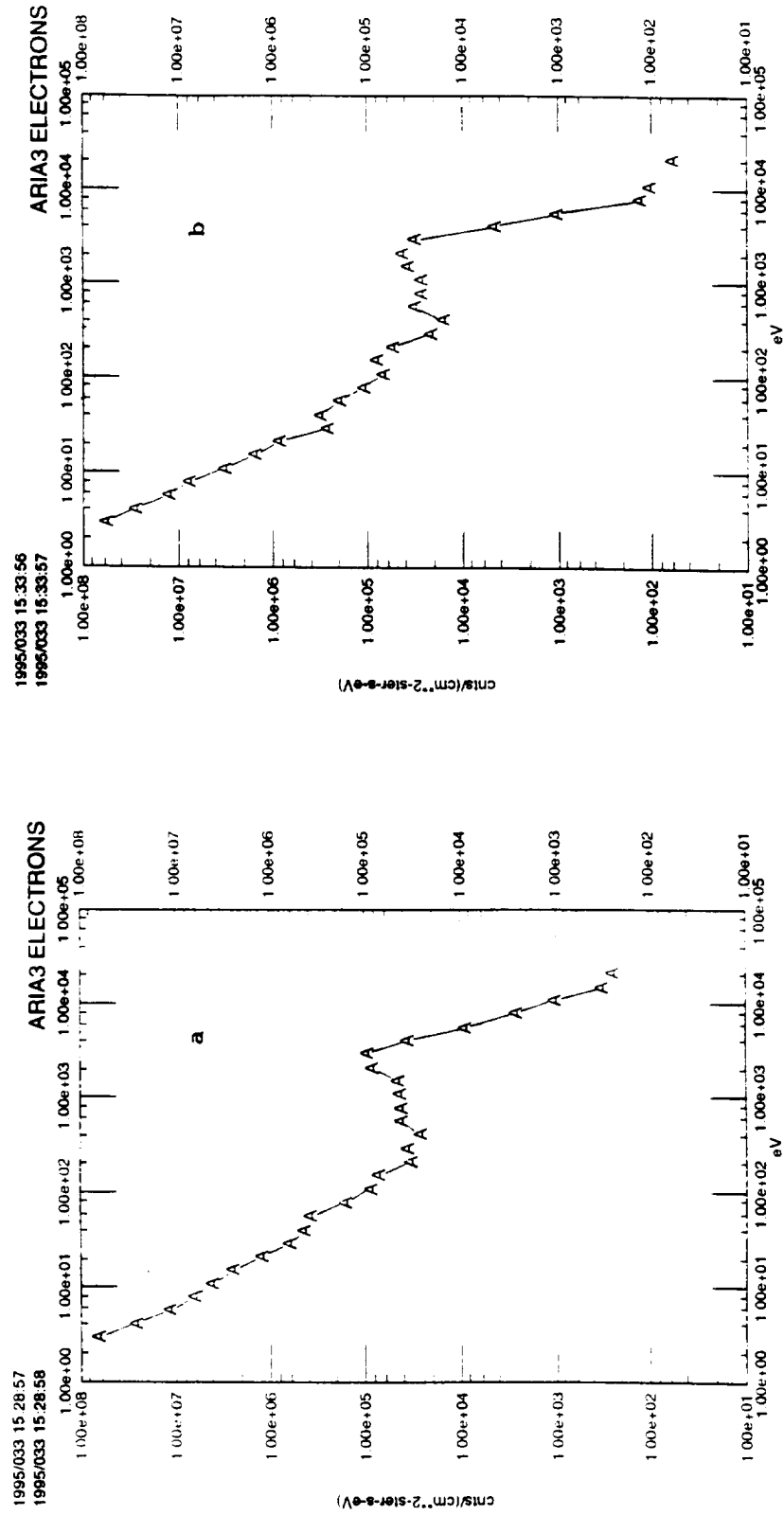


Figure 4. Electron spectra measured within regions of enhanced fluxes on the ARIA 3 flight, (a) at T + 96-97 s and (b) T + 396-397 s.

were measured at the lowest altitudes.

The absorption observed by the ground-based riometer may be a class of morning absorption event known as "slowly varying absorption" (SVA) [Stauning, 1996] in which 'clouds' of energetic electrons are created or injected on closed field lines in the night sector during substorms and gradient-drift into the morning hours. They are observed during the main phase of the substorm and one to several hours afterwards. Although this flight was not optimal because of a failure in the attitude control system, we will continue to pursue it, in part, because of the observation of the absorption.

ARIA 4

ARIA 4 was launched on November 27, 1995, at 0807:24 UT into a stable midnight-sector diffuse aurora. The payload systems performed well. Data from the SPS are shown in Figure 5. The top panel shows the electrons which have a broadly peaked spectrum with a characteristic energy ~ 4 keV initially, decreasing gradually as the payload moved northward to about 2 keV. The only structure in the electron population is seen between 0811:46 and 0812:58 UT (corresponding to an altitude range of 234 km to 203 km). It may be associated with either waves or a potential structure above this location and will be investigated further.

Positive ions are shown in the second panel. At instrument turn-on, they had characteristic energies of 20-30 keV which decreased throughout the course of the flight to about 10 keV. As with the electrons, the ions also decreased in intensity throughout the flight.

Because of the stable nature of the precipitation at the time of the ARIA 4 flight, this is an excellent data set for studying the relationships between particle energy input and subsequent atmospheric effects such as the production of secondary electrons and auroral optical emissions. Initial results of such a study are the subject of a Spring AGU paper, Strickland et al. (1996). A paper by Strickland et al. (1997) which studies the information content of the O/N₂ ratio emission brightness ratios that result from electron impact on the atmosphere, submitted for publication, has now been accepted.

ADDITIONAL STUDIES

Several studies dealing with the particle and optical measurements and their effect on upper atmospheric composition and winds are underway. It is expected that there are several more publications that result from these investigations. An ARIA science team meeting will be held in the spring of 1997 to examine all the ARIA data and to review the status of our papers. When the papers are submitted for publication, a copy will be sent to the NASA program office.

CALIBRATION AND INSTRUMENTATION ISSUES

The same SPS has been flown on all four of the ARIA payloads. The flights covered the time

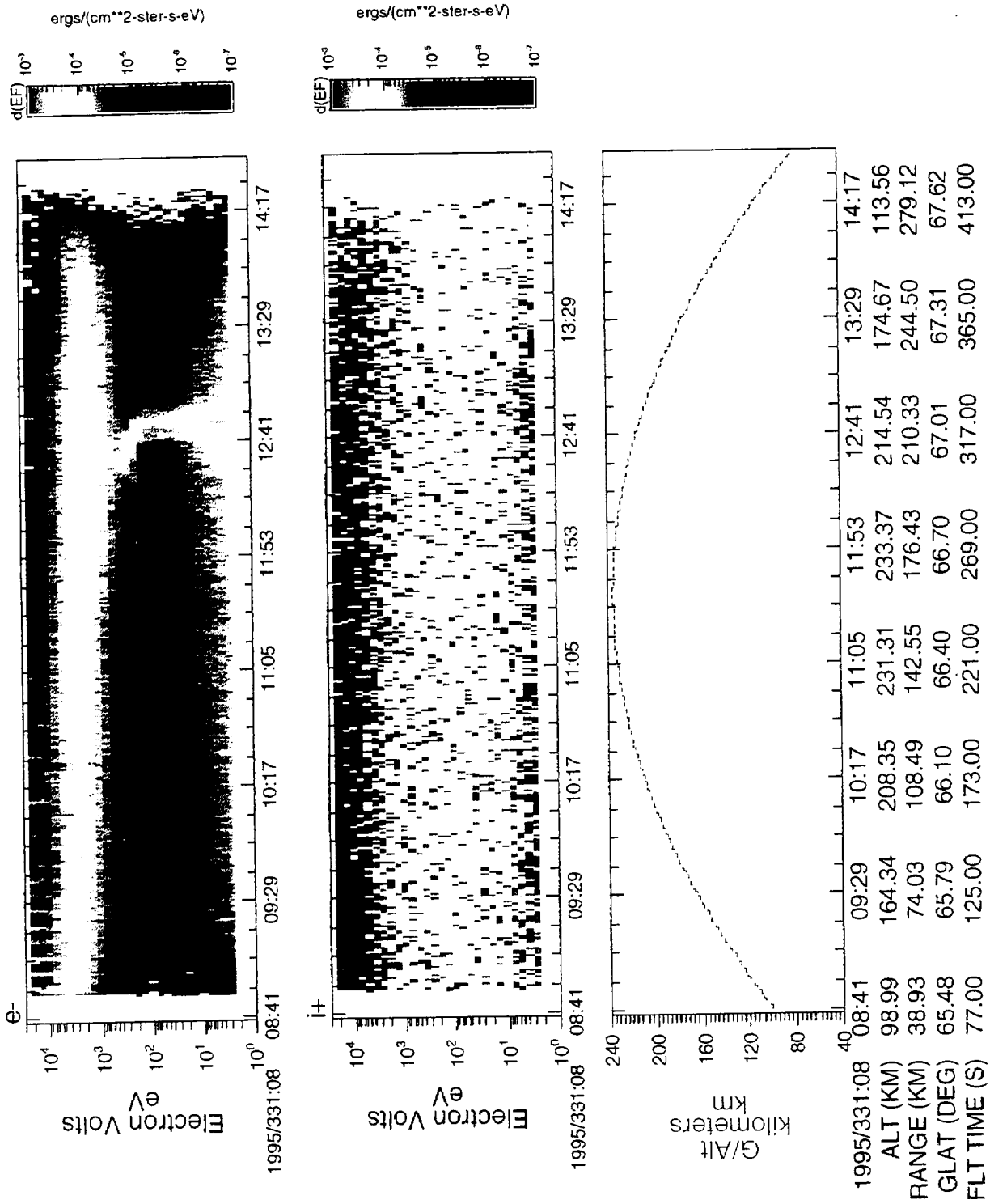


Figure 5. ARIA 4 electron and ion spectrograms measured as the payload crossed a pre-midnight diffuse aurora. The electrons (top panel) have a broadly peaked spectrum with characteristic energy of ~ 4 keV initially and decreasing $T_0 \sim 2$ keV as the payload moved northward across the form. Ions show a similar decrease in characteristic energy from 20-30 keV to ~ 10 keV. The lower panel shows the altitude plot.

period from March 3, 1992 to November 27, 1996. The instrument was calibrated at Southwest Research before the first flight, after the last flight, and at various times between flights. In addition, the electron and ion side counting circuitry was checked in the field before each flight. Remarkably, only small variations were recorded throughout the period. Calibration data representing the energy resolution, the deflection constant, and the throughput constant normalized to the ARIA-1 measurements are shown in Table 1. The throughput constant is used to adjust the geometric factor ($1.79 \times 10^{-4} \text{ cm}^2 \text{ sr}$) for measured variations in detector throughput and is based on the peak value of a spectral measurement of a Ni63 beta source calibration standard.

Examination of the SPS after the ARIA 4 flight indicated difficulty with either the re-entry or the landing of the payload or both. In numerous locations on some of the coated internal surfaces, there were pinpoint sized spots that visually contrasted with the otherwise relatively uniform gray of the Aquadag coating. These were examined under an optical microscope with two types of illumination. Conclusions were that the spots were corrosion products that had erupted through the Aquadag coating. It is speculated that moisture accumulated in the cavity behind the cover, either by direct entry of liquid water or, more likely, by condensation of atmospheric humidity. If this occurred, then surface impurities would have been activated by the presence of moisture, leading to corrosion at sites where a crack or thin spot in the Aquadag coating overlaid a fault in the Alodine finish.

The investigation suggests (a) that we undergo more stringent handling procedures, particularly in preparing the Alodined surfaces for Aquadag treatment, and (b) that in future launch campaigns more attention be given to keeping the payload dry as it is being transported from the impact site back to the launch site.

In spite of the rough re-entry and landing of ARIA 4, post-flight calibration at SwRI indicated almost no change in SPS calibrations between the ARIA 3 post-flight calibrations of February 7, 1995, and the ARIA 4 post-flight calibrations done on January 6, 1996. The same channel multipliers were used on both flights and, in fact, were not removed from the SPS between flights.

PUBLICATIONS AND PRESENTATIONS

The following presentations were made at meetings of the AGU during the grant period.

"Particle Measurements During the ARIA Rocket Campaign," J.R. Sharber, R.A. Frahm, J. Scherrer, J.D. Winningham, G.G. Sivjee, and A.B. Christensen, presented at the 1993 Spring AGU Meeting, abstract in *EOS*, 74, 16, 221, 1993.

"Photometer and Spectrometer Observations During the ARIA Rocket Flight," J.H. Heeht, A.B. Christensen, D.J. Gutierrez, J.R. Sharber, W.E. Sharp, and D.J. Strickland, presented at the 1993 Spring AGU Meeting, abstract in *EOS*, 74, 16, 221, 1993.

Table 1. SPS Calibrations

ARIA Flight and Date	Electron Side				Ion Side				Comments
	CEM	$\Delta E/E$	k (eV/V)	T	CEM	$\Delta E/E$	k (eV/V)	T	
ARIA-1 Mar. 3, 1992	5	0.38	13.58	1	6	0.37	13.45	1	Calibrations of January 1992
ARIA-2 Feb. 12, 1994	4	0.39	13.60	0.915	7	0.39	13.23	0.714	Calibrations of January 1994
ARIA-3 Feb. 2, 1995	5	0.37	13.62	0.883	6	0.36	13.47	0.929	Calibration averages of December 1994 and February 1995
ARIA-4 Nov. 27, 1995	5	0.37	13.62	0.904	6	0.36	13.44	0.952	Calibration averages of February 1995 and January 1996

CEM = channel electron multiplier

$\Delta E/E$ = energy resolution

k = deflection constant (eV/V)

T = throughput constant normalized to ARIA-1 measurements

"E-Region Neutral Zonal Winds in the Postmidnight Diffuse Aurora During the ARIA-1 Rocket Campaign," D.G. Brinkman, R.L. Walterscheid, L.R. Lyons, J.R. Sharber, and M.F. Larsen, presented at the 1993 Spring AGU Meeting, abstract in *EOS*, **74**, 16, 221, 1993.

"Langmuir Probe Measurements on ARIA-1", P.C. Anderson, J.R. Sharber, and G.G. Sivjee, (poster), presented at the 1993 Spring AGU Meeting, abstract in *EOS*, **74**, 16, 223, 1993.

"Observations of Primary and Secondary Electron Spectra in the Diffuse Aurora," J.R. Sharber, R. A. Frahm, A. B. Christensen, D. J. McEwen, J. H. Hecht, K Huang, D. J. Strickland, presented at the Fall Meeting of the AGU, abstract in *EOS Fall Supplement*, **75**, 487, 1994.

"Substorm Associated Particle and Joule Heating in the Diffuse Aurora," P. C. Anderson, A. B. Christensen, P. R. Straus, and J. R. Sharber, presented at the Fall Meeting of the AGU, abstract in *EOS Fall Supplement*, **75**, 487, 1994.

"Substorm Associated Particle and Joule Heating in the Aurora," P.C. Anderson, A.B. Christensen, J.H. Hecht, J.R. Sharber, and D.J. Strickland, presented at the American Geophysical Union, Spring Annual Meeting, abstract in *EOS Spring Supplement*, S189, 1996.

"Rocket and Ground-Based Measurements of Composition Change in the Lower Thermosphere Near Poker Flat Alaska During the ARIA Rocket Flights," J.H. Hecht, A.B. Christensen, D.J. Strickland, and J.R. Sharber, presented at the American Geophysical Union, Spring Annual Meeting, abstract in *EOS Spring Supplement*, S189, 1996.

"A Comparison of Observed and Optically Inferred Neutral Atmospheric Scale Heights During the ARIA/Kayser-II Rocket Flight," P.R. Straus, J.H. Hecht, A.B. Christensen, J.R. Sharber, and D.J. Strickland, presented at the American Geophysical Union, Spring Annual Meeting, abstract in *EOS Spring Supplement*, S190, 1996.

"Analysis of Particle and Zenith Viewing Optical Data from the ARIA I and IV Auroral Rocket Experiments," D.J. Strickland, T. Majeed, J.H. Hecht, A.B. Christensen, and J.R. Sharber, presented at the American Geophysical Union, Spring Annual Meeting, abstract in *EOS Spring Supplement*, S190, 1996.

The following papers have been published during the grant period:

"The ARIA I Rocket Campaign," P.C. Anderson, A.B. Christensen, J.R. Sharber, P.R. Straus, J.H. Hecht, M.F. Larsen, D.C. Kayser, D.J. McEwen, W.E. Sharp, J.A. Koehler, G.G. Sivjee, L.R. Lyons, D.J. Gutierrez, and J.D. Winningham, *J. Geophys. Res.*, **100**, 17265-17283, 1995.

"Observations of the Neutral Atmosphere Between 100 and 200 km Using ARIA Rocketborne and Ground-Based Instruments," J.H. Hecht, A.B. Christensen, D.J. Gutierrez, D.C. Kayser, W.E. Sharp, J.R. Sharber, J.D. Winningham, R.A. Frahm, D.J. Strickland, and D.J. McEwen, *J.*

Geophys. Res., **100**, 17285-17298, 1995.

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CONCLUDING REMARKS

Under this grant two instruments, a soft particle spectrometer and a Langmuir probe, were refurbished and calibrated, and flown on three instrumented rocket payloads as part of the Aerospace Magnetosphere/Thermosphere Coupling program. The flights took place at the Poker Flat Research Range on February 12, 1994 ($T_0 = 1316:00$ UT), February 2, 1995 ($T_0 = 1527:20$ UT), and November 27, 1995 ($T_0 = 0807:24$ UT). In this report the observations of the particle instrumentation flown on all three of the flights are described, and brief descriptions of relevant geophysical activity for each flight are provided. Calibrations of the particle instrumentation for all ARIA flights are also provided. The instruments were successfully flown on all the ARIA flights and therefore contributed in a major way to the success of the entire program. As a measure of this success, the grant investigators have, to date, contributed as co-authors to 10 AGU presentations and three published papers.

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